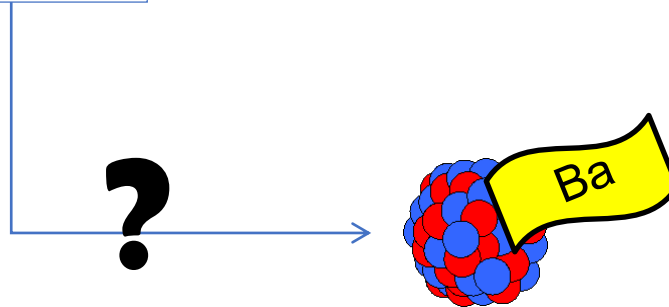
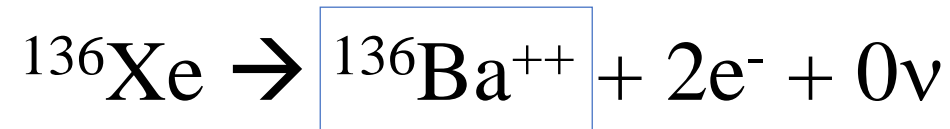


Experiments Beyond the Tonne-Scale: Background Challenges

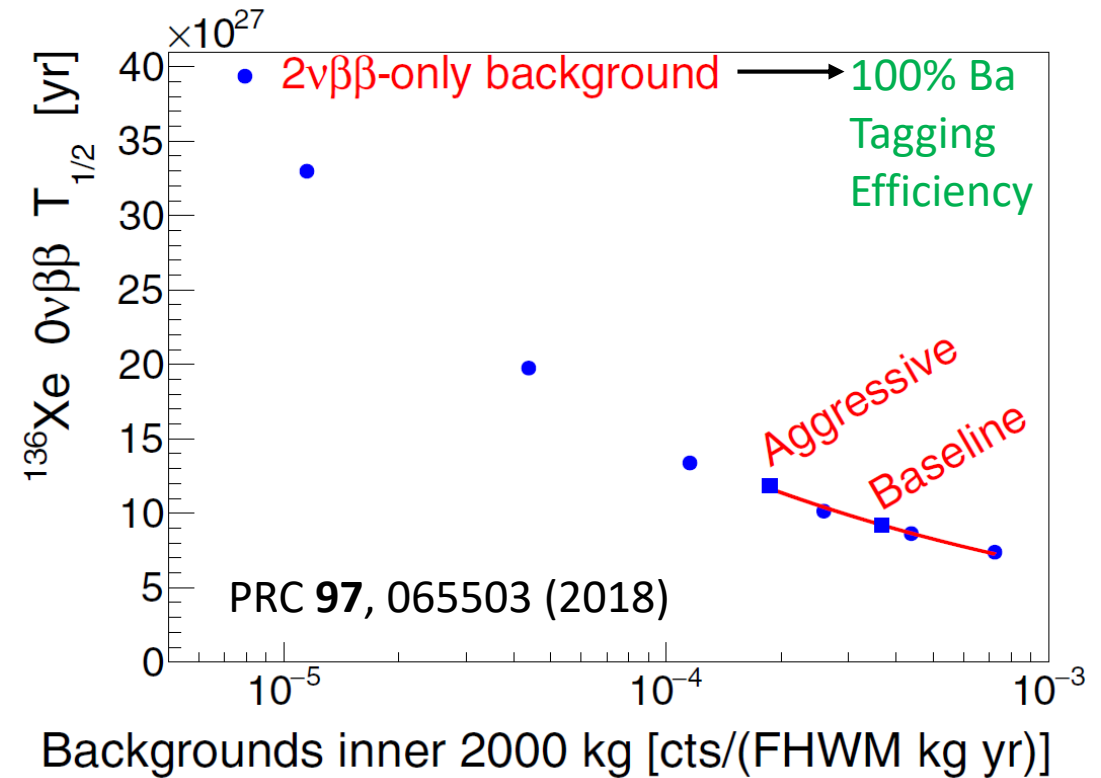
Thomas Brunner (McGill and TRIUMF)

December 10, 2020



Ba-tagging Motivation

- Ba-tagging has potential to improve detector sensitivity.
- Ba-tagging offers a unique possibility to discriminate backgrounds and verify candidate $0\nu\beta\beta$ events as being true $\beta\beta$ decay events.



Sensitivity (blue circles) to the $0\nu\beta\beta$ half-life of a nEXO-like experiment as a function of total background in $Q_{\beta\beta} \pm \text{FWHM}/2$ in the inner 2000 kg.

Ba-tagging concept

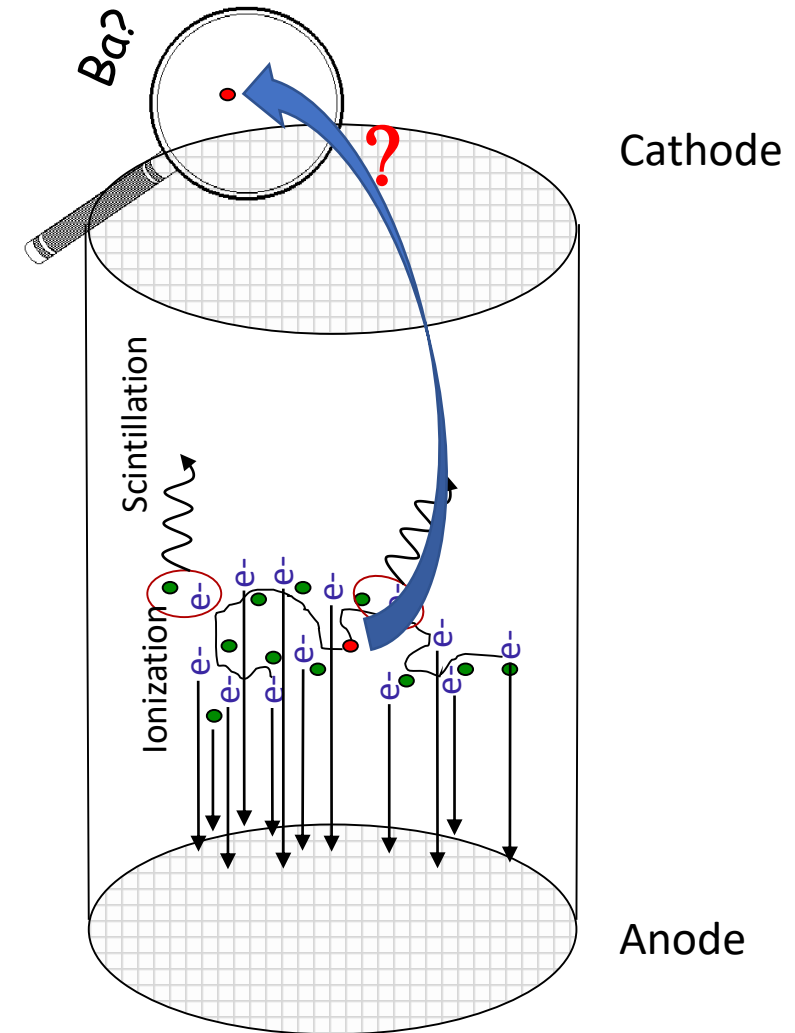
1. Is the event of interest?
 - Close to Q-value?
 - Beta-like event?
2. Localize event
3. Extract ion from detector volume (and separate it from Xe)
4. Identify ion: is it barium?

✓

✓

?

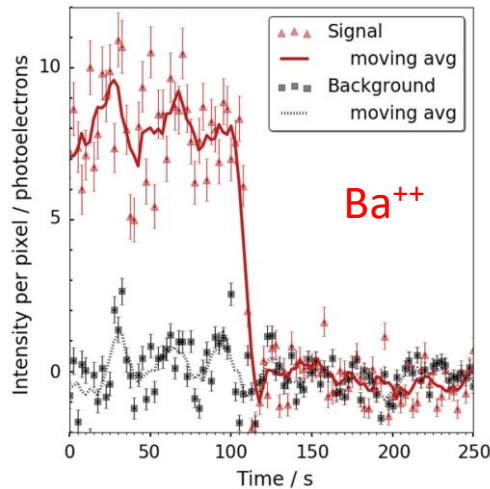
✓



Ba tagging R&D ongoing for liquid- and gas-phase detector

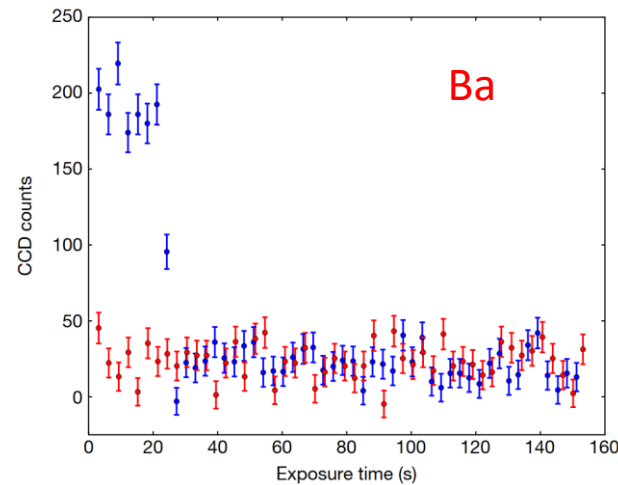
Ba-tagging Status

- A lot of progress over the past years: Detailed studies on ion mobility in Xe, voltage breakdown in Xe, event localization in TPC, See SNOWMASS LOIs for references
- Most notably, several groups demonstrated single-barium sensitivity.



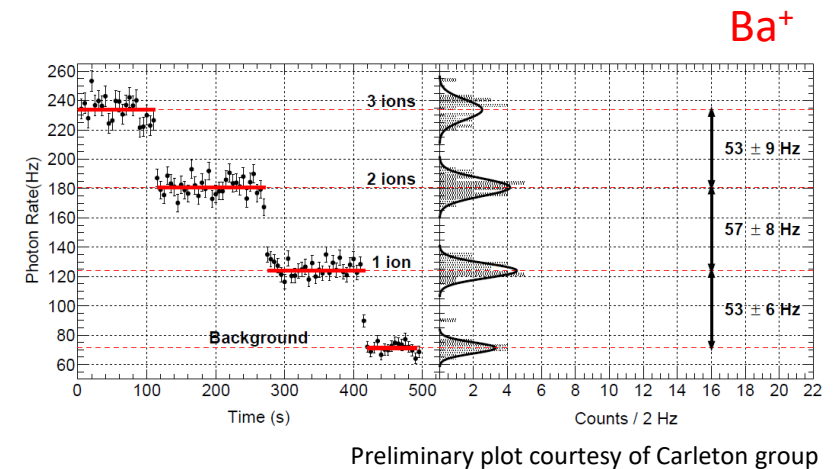
Single-Molecule Fluorescence Imaging

PRL 120,132504 (2018)



Imagine individual Ba atoms in SXe

Nature 569, 203 (2019)



Laser fluorescence spectroscopy on trapped Ba⁺

Demonstrated by M. Green et al., Phys. Rev. A **76** 023404 (2007)

- Transport of ions from decay volume to probe location remains to be demonstrated
 - Drift of Ba-ions to cathode and detect them there – pursued by NEXT collaboration
 - Mechanically insert a probe into the detector to extract Ba(-ions) – pursued by nEXO collaboration

The ion extraction challenge

- Ion-extraction is challenging and warrants investigation of several techniques for GXe and LXe.
- Methods required and being proposed to quantify extraction process.
- Despite great progress, a full solution *in my opinion* is still *N* years out.
- Current R&D is performed within collaboration ‘boundaries’.
- Would Ba-tagging benefit from mixing-and-matching techniques?
- Beyond the next-generation $0\nu\beta\beta$ experiment, should there be more coordination among Ba-tagging groups or even a collaboration?

LOIs submitted to the SNOWMASS2021 process

Barium Tagging in Xenon Gas for $0\nu\beta\beta$ Decay, and The NEXT-SABAT R&D for Barium Tagging, NEXT collaboration

- SMFI for ion detection of Ba^{++}
- RF carpet proposed to concentrate Ba^{++} ions in small spot ('ion to detector') **or** Laser interrogation on cathode ('detector to ion')
- Tests planned with radioactive ^{144}Ba ions from ^{252}Cf at CARIBU facility at ANL, with Ra^{++} (Ra has similar ionization energies as Ba) and low energy Ba beams
- Goal: implementation in demonstrators (NEXT-White, NEXT-CRAB) followed by NEXT-HD

Barium tagging for a nEXO upgrade and future ^{136}Xe $0\nu\beta\beta$ detectors,

W. Fairbank et al.

- Two methods proposed applying laser fluorescence for Ba identification: Ba trapped in SXe on cryo probe **or** Ba-ion extraction from LXe to GXe with capillary and subsequent extraction into vacuum
- R&D on 3D daughter extraction from LXe with probe ongoing in 100-kg LXe TPC
- Various ion sources under consideration; plans to implant radioactive Cs or La isotopes in LXe at TRIUMF and/or the creation of Cs isotopes by (p,n) reactions in LXe at the University of Kentucky → observe decay to Ba, 'tag' Ba
- Planned as future upgrade for nEXO